Acceptable regulations to reduce common resource extraction*

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Abstract

Regulating open access resources is welfare enhancing for society but not necessarily for all users. Some of them may, therefore, oppose regulation. We examine the short-term impact of common resource regulations under the political feasibility constraint that no user should lose from free access extraction. We find that market-based instruments such as fees and subsidies or transferable quotas achieve a higher and more efficient reduction of resource extraction than non-transferable quotas. However, they exacerbate inequalities whereas quotas tend to reduce them.

Key Words: common-pool resource, regulation, quota, political feasibility, fishery.

JEL classification: H23, Q22, Q28.

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1 Introduction

Since at least Gordon (1954) and Hardin (1968), it has been well known that the open access extraction of natural resources (e.g. clean air, water, fish, forests) leads to over-exploitation. Efficiency can be improved under regulated extraction. Consistently, natural resource extractions have been extensively regulated worldwide. For instance, in the fishing industry, several regulatory tools have been implemented to reduce over-fishing, including access rights, vessel buy-backs, quotas and fishing restrictions. Such regulations have heterogeneous impacts on the fishermen's welfare. Although some might improve their situation compared to open access, other might lose out and therefore strongly oppose regulations. Despite being welfare-improving for the fishing industry as a whole, regulations might encounter strong opposition and thus be difficult to implement. The political feasibility of new fishing regulations should take into account their acceptability by the fishing industry, on the basis of individual welfare.

This paper examines the performance of regulatory instruments in reducing resource extraction under the "political feasibility constraint" that every user should be better off with the regulation than without it. How far can the regulation go in reducing resource extraction without hurting users in the short run? Another dimension of political feasibility is equity. Natural resource exploiters such as fishermen might oppose a regulation that exacerbates inequalities. We consider equity in addition to efficiency as criteria to rank regulations.

We focus on three regulatory instruments. The first is an access fee to the resource and a subsidy for those who stop extraction (e.g. a boat buy-back for fisheries). This is referred to as the fee and subsidy (FS) scheme. It must be budget-balanced, i.e. the subsidies must be entirely financed by the fees collected.[1] The second instrument is an individual, uniform and non-transferable quota (IQ). It imposes restrictions or quotas on inputs (e.g. fishing days, net or vessel size) or output (e.g. catch). The third instrument allows the users (e.g. fishermen) to exchange their quotas (on input or output) in a

[1]Note that in our framework an access fee is equivalent to a tax on output (e.g. catch) in equilibrium.

competitive market. It is referred to as the individual transferable quota (ITQ) scheme.

The FS, IQ and ITQ regulations are commonly used to regulate fisheries. For instance, in the Bering Sea, National Marine Services implemented crab fishery boat buy-backs and landing fees to reduce the crab decline. The buy-backs were financed by a loan to be repaid over 30 years by catch landing fees of crab fishermen who remained in the fishery. There are different types of quota. Input restrictions such as vessel size, maximal season length, net size and fishing techniques are individual and non-transferable quotas on inputs. Individual and non-transferable quotas on outputs are also applied. For instance, the United Kingdom divides its allowable catch as fixed by the European Union among groups of fishermen through individual quotas on catches. Individual and transferable quotas are more and more popular worldwide, especially in New Zealand, Australia, Canada and the United States.[2]

To asses the acceptability of the above regulations in a simple model, we employ the following modelling strategy. First, since we focus on the short-term impact of regulations, we rely on a static model of common resource extraction à la Gordon (Gordon 1954), thereby abstracting for dynamic considerations such as the evolution of the resource stock. Over-extraction is inefficient in the short run (e.g. the current fishing season) because it reduces the return of user's investment in the extraction effort.[3] Second, to capture the efficiency gain of market-based regulations (FS and ITQs) and to be able to analyse inequality, we need some heterogeneity in the user population, say among fishermen. We therefore introduce a heterogeneous but constant marginal extraction cost.[4] As with homogenous cost, under free access, fishermen extract the resource provided their profit is positive. But with heterogenous costs only the fisherman with highest cost makes no gain from fishing; all others obtain a strictly positive profit. Out

[2]Documented examples can be found in Bjorndal and Munro (1998), Hannesson (2004).

[3]In a static framework, free access extraction leads to inefficient extraction because the return of one extraction effort is the average product (and *not* the marginal product) which is equalized to marginal cost in equilibrium (see e.g. Weitzman, 1974, Baland and Platteau, 1996).

[4]Marginal costs are private information which rules out heterogeneous regulations such as quotas or taxes contingent on marginal costs.

of the fear of losing this profit, they might therefore be reluctant to agree to regulations.

The goal of a regulation is to reduce the total fishing effort under the constraint that no fishermen get less than their free-access profit. We provide necessary and sufficient conditions for the implementation of a targeted fishing effort under the political feasibility constraint for the three regulations. In our framework, FS and ITQs are equivalent since they yield the same outcome in equilibrium. These conditions imply that the two market-based instruments (FS and ITQs) implement at least the same fishing effort than IQs but can reduce it further. Furthermore, the same targeted fishing effort is more efficiently implemented by FS and ITQs than by IQs since the former regulations select the more efficient fishermen. The less efficient fishermen accept the boat buy-back (under FS) or sell all their quotas (under ITQs). In contrast, if quotas are non-transferable (under IQs), all fishermen still fish but with reduced effort or inputs. Consequently, FS and ITQs yield higher individual and total welfare.

Although market-based instruments tend to dominate IQs regarding efficiency, they have two fairness drawbacks. First, by rewarding some agents for not fishing (through vessel buy-backs or the quotas sold) the market-based regulations assign part of the welfare to non-fishermen. These outsiders benefit from the fishing industry without contributing to it. Even worse, they experience the highest welfare improvement from free access. In contrast, under IQs, the welfare is entirely distributed to fishermen. Second, the FS and ITQ schemes do not change the distribution of welfare among fishermen whereas IQs reduce inequality. Moreover, inequality is reduced further with more stringent quotas.

This paper is related to the theoretical literature on common-pool resource extraction. Most of this literature focuses on the emergence and enforcement of endogenous extraction rules. Users play a common-pool resource game in which they might voluntarily refrain from extraction and possibly even punish those who do not do likewise (Ostrom 1990, Sethi and Sommanathan, 1996, Dayton-Johnson and Bardhan,2002, Baland and Platteau, 2003).[5] In contrast, here we consider exogenous regulations imposed

[5]In the same vein, Burton (2003) studies the problem of rule enforcement and explores how sanctions

on users. We examine the voluntary adherence to those rules by selfish users who fully comply with them. In particular, we investigate how far the regulator can go in reducing extraction without hurting them.

Several papers have examined the welfare and distributional impact of a specific regulation of a common resource, namely privatization. Privatization improves total welfare but might reduce individual welfare because users earn the marginal product rather than the average product (Weitzman, 1974, De Meza and Gould, 1987) or are exposed to more risk (Baland and Francois, 2005).[6] Here we focus on other regulations which also improve total welfare but have non-trivial impacts on individual welfare. Those regulations do not exclude some users but rather regulate their activity.

In the economics of fisheries, several papers compare fishery regulations but with a different focus. Androkovich and Stollery (1991) and Weitzman (2002) consider homogeneous fishermen who face uncertainty in estimating the fish stock size and the demand for fish. They argue that price-based instruments such as landing fees are more efficient than quantity-based ones such as individual quotas. With deterministic fish stock and demand but with heterogenous fishermen, as assumed here, those two regulations lead to the same equilibrium outcome as long as quotas are transferable. Johnson and Libecap (1982) discuss how heterogeneity in fish skills affects regulation acceptability. They highlight the fact that *"without side payments (...), uniform quotas could leave more productive fishermen worse off than under common property conditions"*. Consistently, in our model the more efficient fishermen are those who experience the lowest welfare improvement under IQs and therefore bind the "political feasibility constraint". Johnson and Libecap also suggest that egalitarian pressure favours uniform quotas. We rationalize this claim by showing than IQs reduce inequalities while ITQs exacerbate them.[7]

affect heterogeneous fishermen within a community, using limited entry and uniform quotas.

[6] In contrast, Ambec and Hotte (2006) argue that users deprived of their common property rights might benefit from privatization by extracting the resource illegally.

[7] In the same strand of literature, Clarck, Munro and Sumaila (2005) study the impact of buy-back subsidies on fisheries previously extracted under open-access in a dynamic framework. They highlight

The paper is organized as follows. After presenting the model and free access regime in Section 2, we consider successively the three regulatory instruments: the fee and subsidy scheme (Section 3), non-transferable quotas (Section 4) and transferable quotas (Section 5). We compare the three instruments in Section 6. Section 7 concludes the paper.

2 The model

A community of individuals are extracting a natural resource from a common pool. Typical examples of such common-pool natural resources include fisheries, forests for timber or fuel-wood, hunting grounds and pastures. For the sake of simplicity, the common-pool resource will be called the "fishery" and the extractors the "fishermen", although the model is applicable to other common-pool resources.

Each fisherman selects a fishing effort x. For every fishing effort, a fisherman obtains the average product of extraction $\phi(X)$ where X is the total fishing effort. The average product is assumed to be decreasing in the fishing effort, i.e., $\phi' < 0$. Fishermen are endowed with the same effort capacity $\bar{x}$ but differ by their fishing cost. They are labelled according to their constant marginal cost of fishing c which is private information. The fishing cost includes wages, the annual cost of a vessel, fuel, and the price of other inputs. It might also include the opportunity cost of spending this time and money in fishing. Moreover, heterogeneous fishing costs might capture differences in fishing skills since to obtain a same "fishing effort" some fishermen might need to spend more inputs (e.g. time in the fishery). There is a continuum of fishermen (of mass 1) with costs $c \in [\underline{c}, \bar{c}]$ (with $0 < \underline{c} < \bar{c}$) distributed according to the cumulative $G(c)$ and density $g(c)$. The price of the resource is normalized to 1. When investing x units of fishing effort, the fisherman c obtains $\pi(c) = x(\phi(X) - c)$ from the fishery.[8]

the fact that fishermen's anticipation of future buy-backs might lead to overcapacity. They suggest the implementation of "incentive-adjusting approaches to management". We assume here that fishermen do not anticipate the buy-back regulation, which avoids the overcapacity problem.

[8] If c includes only opportunity costs, the fisherman's payoff on fishing is $x\Phi(X)$, and the remaining

We first consider the benchmark free-access (FA) extraction framework. In our set-up, it is easy to show that, under free access, there exists a threshold cost c^{FA} such that fishermen with lower costs fish up to their capacity $\bar{x}$ while the others do not fish at all. For a given equilibrium fishing effort X^{FA}, a fisherman obtains the average product $\phi(X^{FA})$ per unit of effort. He fishes so long as his benefit exceeds his marginal cost c. Denote c^{FA} the fishermen whose marginal cost equals the free-access average product, i.e,

$$c^{FA} = \phi(X^{FA}). \tag{1}$$

All fishermen with c lower than c^{FA} obtain more than their marginal cost per unit of effort. They fish up to their capacity $\bar{x}$. Fishermen whose cost is higher than c^{FA} lose out for each unit of effort. They do not fish. We therefore do not call them fishermen anymore but simply "agents".[9] The total fishing effort under FA is thus:

$$X^{FA} = \int_{\underline{c}}^{c^{FA}} \bar{x} dG(c) = \bar{x}G(c^{FA}). \tag{2}$$

Figure 1 below illustrates the FA equilibrium

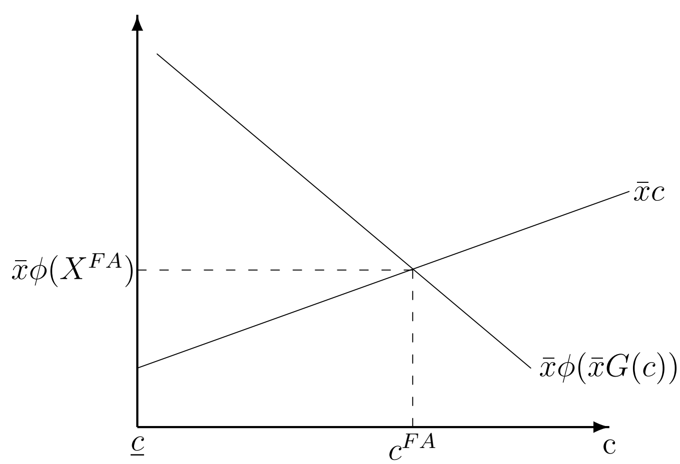

Figure 1. *Extraction under free access*

units $\overline{x} - x$ are invested in an outside activity which yields $(\overline{x} - x)c$ to fishermen c.

[9]In the rest of the paper we call "fishermen" those whose costs are lower than c^{FA}, i.e., who fish under free access.

The downward sloping curve $\bar{x}\phi(\bar{x}G(c))$ represents the benefit from fishing $\bar{x}$ units of effort when fishermen with costs up to c fish at their maximal capacity. The upward sloping curve is the total costs of the fisherman c when exerting effort $\bar{x}$. The threshold fisherman under FA c^{FA} makes zero profit from fishing (see condition (1)), meaning that his benefit $\bar{x}\phi(X^{FA})$ is equal to his cost of fishing $\bar{x}c^{FA}$. It is therefore defined where the above two lines cross. Each fisherman $c < c^{FA}$ makes a strictly positive profit equal to the distance between his benefit at the equilibrium $\bar{x}\phi(X^{FA})$ (the dotted line) and his total cost $\bar{x}c$ on the upward sloping curve. Fisherman c's profit under open-access for every $c \leq c^{FA}$ is thus:

$$\pi^{FA}(c) = \bar{x}[\phi(X^{FA}) - c]. \tag{3}$$

The FA regime is inefficient because fishermen extract the resource until the marginal cost is equal to the average product instead of to the marginal product. This is the well-known over-exploitation result of open access extraction of natural resources. Fishing effort must be reduced to restore or, at least, increase efficiency. This is indeed the goal of regulations.

In the next three sections we examine the performance of regulations in implementing a targeted fishing effort $X < X^{FA}$ under the political feasibility constraint of Pareto improvement from free-access. The targeted fishing effort could be the one that maximizes the fishing industry's welfare in the short run. But this first-best fishing effort might not be unanimously acceptable. Moreover, if the fishing stock exhibits some positive externalities outside the fishing industry, for instance for its biodiversity value or impact on tourism, it might be optimal to reduce the fishing effort further.[10] The question is: how far can we go in reducing fishing efforts without hurting fishermen? We answer this question by considering successively three regulatory instruments: a fee and subsidy scheme (FS) in Section 3, individual quotas (IQs) in Section 4, and individual transferable quotas (ITQs) in Section 5.

[10] In this case a subsidy to the fishing industry might be justified. By relaxing the budget balance constraint of the fee and subsidy scheme, it might help to meet the political feasibility constraint.

3 The fee and subsidy scheme

The first regulatory instrument is an access fee τ and a subsidy σ for those who agree to quit the fishing industry. Only active fishermen in the free-access regime can apply for the subsidy. It can take the form of boat buy-backs or unemployment and reconversion benefits. The fee and the subsidy are the same for all fishermen.[11] The FS scheme must be budget balanced in the sense that all subsidies must be entirely financed by the fees collected.

The FS regulation raises the cost of fishing by τ and the benefit from not fishing by σ. Fisherman c's profit with a fishing effort $x > 0$ is thus $x[\phi(X) - c] - \tau$ and σ if $x = 0$. As with under free-access, those fishermen whose cost is lower than a threshold level fish up to their capacity while those with a cost higher cost do not fish. The threshold cost denoted $\tilde{c}$ depends on both τ and σ. It is defined by:

$$\bar{x}[\phi(X) - \tilde{c}] - \tau = \sigma. \tag{4}$$

The threshold fisherman $\tilde{c}$ is indifferent to fishing or not. He obtains the same profit while fishing (left-hand side of (4)) or not fishing (right-hand side of (4)). The total fishing effort obtained under this regulation is:

$$X = \int_{\underline{c}}^{\tilde{c}} \bar{x} dG(c) = \bar{x}G(\tilde{c}). \tag{5}$$

Combining (4) with (5) leads to the following *incentive-compatibility* constraint:

$$\bar{x}[\phi(\bar{x}G(\tilde{c})) - \tilde{c}] - \tau = \sigma. \tag{6}$$

The scheme (τ, σ) leads to the threshold fisherman $\tilde{c}$ that satisfies (6). All fishermen with $c < \tilde{c}$ fish up to their capacity $\bar{x}$.

The FS scheme (τ, σ) increases the cost of fishing by $\tau + \sigma$, as fisherman c has to pay τ but also give up to the subsidy σ if he fishes. Therefore his cost of fishing $\bar{x}$ units of effort is now $\bar{x}c + \tau + \sigma$. This is represented in Figure 2 below.

[11] It would be more efficient to define an access fee and a subsidy contingently on c. However, it is not feasible here because c is private information.

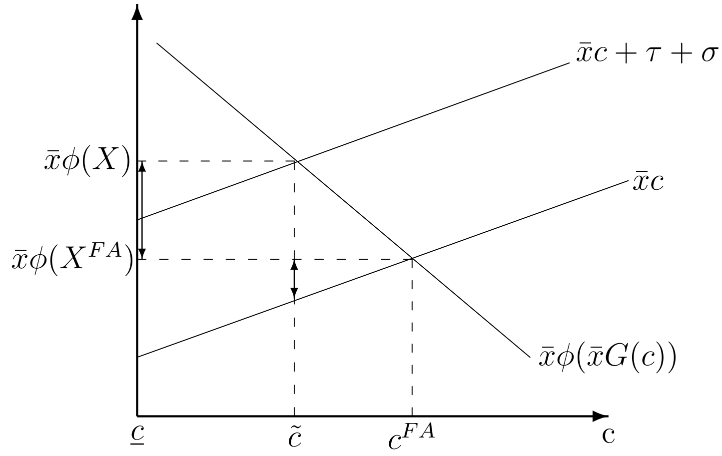

Figure 2. *Extraction with an access fee and subsidy scheme.*

The regulation (τ, σ) moves upward the total costs line of $\bar{x}$ units of effort in Figure 2. The fisherman $\tilde{c}$ who is indifferent to fishing or not is defined where the new cost curve $\bar{x}c + \tau + \sigma$ crosses the benefit curve $\bar{x}\phi(\bar{x}G(c))$. The fishing effort implemented is $X = \bar{x}G(\tilde{c})$. Each fisherman with $c < \tilde{c}$ fishes and makes a strictly positive profit which is equal to the distance between the equilibrium benefit $\bar{x}\phi(X)$ and his total cost $\bar{x}c + \tau$. Those with $c > \tilde{c}$ obtain the subsidy σ.

Now, the FS scheme (τ, σ) must satisfy the following budget-balanced constraint:

$$\tau G(\tilde{c}) \geq \sigma(G(c^{FA}) - G(\tilde{c})). \tag{7}$$

Combining the incentive constraint (4) with the budget balance (7) leads to:

$$\tau = \bar{x}\left[\phi(X) - \tilde{c}\right]\left(1 - \frac{G(\tilde{c})}{G(c^{FA})}\right), \tag{8}$$

$$\sigma = \bar{x}\left[\phi(X) - \tilde{c}\right]\frac{G(\tilde{c})}{G(c^{FA})}, \tag{9}$$

The incentive constraint (4) forces $\tau + \sigma$ to be equal to the threshold fisherman's profit $\bar{x}\left[\phi(X) - \tilde{c}\right]$. The budget balance constraint divides this profit between the fee τ and the subsidy σ. The share of the fee and subsidy depend on the ratio of remaining fishermen under the new regime $\frac{G(\tilde{c})}{G(c^{FA})}$. A higher reduction of resource extraction leaves less fishermen on the fishery and more outside. Therefore the fee τ must be increased to cover the cost of subsidizing more fishermen from not fishing. Although each remaining fisherman pays more, each of those who give up fishing receives less.[12]

To sum up, a budget-balanced access-fee and subsidy scheme that implements a total fishing effort X yields to each fisherman $c \leq \tilde{c}$ a payoff,

$$\pi^{FS}(c) = \bar{x}[\phi(X) - c] - \bar{x}\,[\phi(X) - \tilde{c}]\left(1 - \frac{G(\tilde{c})}{G(c^{FA})}\right) \tag{10}$$

and to each fisherman with $c \geq \tilde{c}$,

$$\pi^{FS}(c) = \bar{x}\,[\phi(X) - \tilde{c}]\,\frac{G(\tilde{c})}{G(c^{FA})}, \tag{11}$$

where threshold fisherman is defined by the unique cost $\tilde{c}$ such that $\bar{x}G(\tilde{c}) = X$.

We now compare these profits with the ones obtained under free access to asses the political feasibility of the FS scheme (τ, σ). We want the regulation to be accepted by *all* fishermen in the sense that everybody (those who still fish and those who leave this activity) must be better off under the regulation than under FA. Formally, the following *political feasibility constraint* must hold for every $c \leq c^{FA}$:

$$\pi^{FS}(c) = \max\{\bar{x}[\phi(X) - c] - \tau, \sigma\} \geq \pi^{FA}(c). \tag{12}$$

Combining (3), (4), (12) and (7) lead to:

$$\frac{\bar{x}[\phi(X^{FA}) - \tilde{c}]}{\bar{x}[\phi(X) - \tilde{c}]} \leq \frac{X}{X^{FA}}. \tag{13}$$

An acceptable FS scheme implements any effort level X that satisfies inequality (13) where $\tilde{c}$ is defined in (4). In a nutshell, the threshold fisherman $\tilde{c}$ should obtain a ratio of profit improvement (left-hand side in (13)) not higher than the relative reduction in the fishing effort (right-hand side in (13)).

It turns out that (13) is also a sufficient condition for a targeted fishing effort X to be implemented under the political feasibility constraint with a FS scheme. It is easy to

[12]Note that with extra funds, i.e. if the budget-balancing is relaxed, the same target effort X can be obtained with a lower fee and/or a higher subsidy while $\tau + \sigma$ remaining unchanged to satisfy the incentive constraint.

show that if (13) holds then (τ, σ) defined above is acceptable to and incentive-compatible for fishermen (i.e. satisfies conditions (4) and (12)). We thus established the following necessary and sufficient condition for the implementation of a target fishing effort with a Pareto-improving FS scheme.

Proposition 1 *A Pareto-improving fee and subsidy scheme implements a fishing effort X if and only if*

$$\frac{\bar{x}[\phi(X^{FA}) - \tilde{c}]}{\bar{x}[\phi(X) - \tilde{c}]} \leq \frac{X}{X^{FA}},$$

with $\tilde{c}$ such that $\bar{x}G(\tilde{c}) = X$.

Before moving on to quotas, it is worth to mentioning that, in our model, the access fee policy is equivalent to a tax rate on fishing effort or on catch at the equilibrium. More precisely, the same reduction of the fishing effort with the same individual profit can be obtained with a tax rate $\frac{\tau}{\bar{x}}$ on each unit of input x (e.g. labor, fishing supply, fuel) or a tax $\frac{\tau}{\bar{x}\phi(X)}$ on catch or output $x\phi(X)$ instead of an access fee τ.[13] We now examine an alternative regulatory instrument that reduces fishing efforts: individual quotas.

4 Individual Quotas

Consider first a uniform individual and non-transferable quota (IQ) on fishing efforts. Fishermen are allowed only $\hat{x}$ units of fishing effort with $\hat{x} < \bar{x}$. Examples of such regulations include fishing season restrictions, specific equipment or size of vessels. It only applies to fishermen active under FA, i.e. those with $c < c^{FA}$.[14]

[13] This equivalence is mostly due to our assumption of a constant marginal cost which provides incentives to use full effort capacity with per input or per output tax rates once the fisherman has decided to renounce to give up the subsidy.

[14] If everybody can fish up to the quota, since the average product becomes higher than c^{FA}, then some fishermen with $c > c^{FA}$ who did not fish under free access will fish under the IQ regime. A higher fishing effort reduction can be achieved by assigning quotas only to the active fishermen under FA.

The IQ regime has two impacts. First, it restricts entry to fishermen $c \leq c^{FA}$. Second, it reduces the individual effort capacity to $\hat{x}$. As before, fishermen fish up to their allowed capacity now $\hat{x}$. The total fishing effort implemented is:

$$X = \int_{\underline{c}}^{c^{FA}} \hat{x} dG(c) = \hat{x} G(c^{FA}),$$

which is obviously lower than under free access. Therefore the average product is higher, i.e., $\phi(X) > \phi(X^{FA})$. Hence, implementing a fishing effort X under IQs requires assigning the following quota level to every fishermen :

$$\hat{x} = \frac{X}{G(c^{FA})}. \tag{14}$$

The equilibrium profit of a fisherman c is:

$$\pi^{IQ}(c) = \frac{X}{G(c^{FA})}[\phi(X) - c] \tag{15}$$

As before, we want the regulation to be acceptable to all (Pareto improving). An individual quota level $\hat{x}$ is acceptable to fisherman c if his profit is not lower than under FA, formally if:

$$\hat{x}[\phi(X) - c] \geq \bar{x}[\phi(X^{FA}) - c].$$

The above *political feasibility condition* of IQs must be satisfied for every fisherman. It can be rewritten as,

$$c(\bar{x} - \hat{x}) \geq \bar{x}\phi(X^{FA}) - \hat{x}\phi(X), \tag{16}$$

for every $c \leq c^{FA}$. The right-hand term in (16) is the variation of catch or total revenue. Its sign is ambiguous. Although fishermen experience an increase of their catch per unit of effort (i.e. ϕ increases), since the effort level is lower, the total harvest and therefore the total revenue (formally $x\phi$) might decrease. If revenues increase or remain equal, i.e. if the right-hand term in (16) is positive or nil, then the acceptability condition holds for every fisherman. If they decrease, i.e. if the right-hand term in (16) is strictly negative, then political feasibility might be a problem. In that case, some fishermen might lose out under the regulation. The left-hand term in (16) is the total cost saved by reducing the fishing effort. It is lower for fishermen with a low cost of fishing effort. For IQs to be accepted by all, it should be accepted for the ones with lower fishing cost $\underline{c}$. Formally, a necessary and sufficient condition for the acceptability condition (16) to hold for all fishermen is the fact that it holds for fisherman $\underline{c}$, i.e.,

$$\frac{\phi(X^{FA}) - \underline{c}}{\phi(X) - \underline{c}} \leq \frac{\hat{x}}{\bar{x}}.$$

Using (2) and (14), straightforward computation shows that the above inequality is equivalent to the next one in Proposition 2.

Proposition 2 *Individual quotas implement a fishing effort X if and only if*

$$\frac{\bar{x}[\phi(X^{FA}) - \underline{c}]}{\bar{x}[\phi(X) - \underline{c}]} \leq \frac{X}{X^{FA}}. \tag{17}$$

Proposition 2 establishes that X can be implemented with IQs if the profit improvement of the most efficient fisherman $\underline{c}$ (left-hand side) is lower or equal to the decrease in aggregate effort (right hand side). As pointed out by Johnson and Libecap (1982) those fishermen who are the most likely to lose out and therefore to oppose the introduction of individual quotas are the most efficient ones. The IQ regulation is illustrated in Figure 3 below.

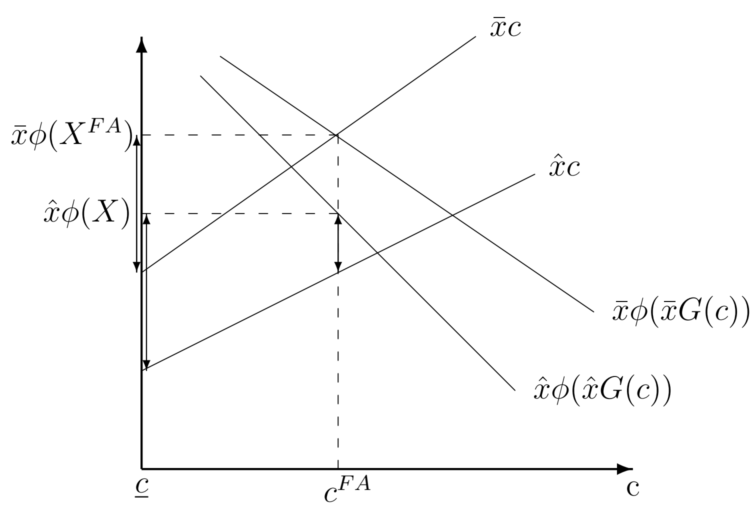

Figure 3. *Regulation with IQ*

The downward sloping curves represent the total product under free access (using full capacity $\bar{x}$) and under IQs (using all effort quota $\hat{x}$). Here we consider the worst case for fishermen whereby the total product is always lower under IQs. The upward slopping curves are total costs. All fishermen with costs up to c^{FA} exhaust their quotas to fish. Every fisherman c earns a strictly positive profit which is equal to the distance between the equilibrium total revenue $\hat{x}\phi(X)$ and his total cost $\hat{x}c$. Yet his profit has not necessarily improved compared to the free access regime. Recall that a fisherman c's free access profit is the distance between the free access revenue $\overline{x}\phi(X^{FA})$ and the total cost $\bar{x}c$. Here IQs reduce revenues but also total costs. Although the reduction of revenue is identical for all fishermen, the reduction of total costs is heterogeneous. Those with higher costs per unit of effort experience a higher reduction of total cost and therefore a higher increase of profit. In particular the fisherman with the highest cost c^{FA} obtains the highest profit increase, represented by the right-hand double arrow in Figure 3.[15] On the other hand, the fishermen with the lowest cost $\underline{c}$ (the more "efficient") get the lowest increase of profit. In Figure 3 this increase is almost nil because the profits under FA and under IQs (the size of the two left-hand double arrows) are almost the same. In other words, the political feasibility constraint (17) is binding here. This difference of total cost (and thus profit) among fishermen is due to the difference of slopes of the two total cost curves which increase with lower quotas $\hat{x}$. By reducing the slope of the total cost curve, IQs tend to "homogenize" fishermen's total costs.

Before moving on to transferable quotas, note that, in our framework, the individual quota can equivalently be defined on individual catch or revenue. A upper bound on harvest $\bar{\phi} = \hat{x}\phi(X)$ provides every fisherman with incentives to exhaust their quota, thereby exerting fishing effort $\hat{x}$ at the equilibrium.

[15]Remember that fishermen c^{FA} make zero profit under free access so that their increase of profit is simply their profit under the IQ regime.

5 Individual and Transferable Quotas

Consider the following individual and transferable quota (ITQ) scheme. As in the preceding section, each fisherman $c \leq c^{FA}$ is assigned an individual level of quotas on effort $\hat{x}$. But now quotas can be exchanged in a competitive quota market at a price p. The total quota level distributed is $X = \hat{x}G(c^{FA})$.

Each fisherman compares the return of one unit of quota in the fishery with its value on the market. By using for himself the quota to fish, a fisherman c obtains $\phi(X) - c$. On the other hand, he gets p by selling this unit on the market. Therefore, a fisherman c prefers to sell (respectively buy) a quota if $\phi(X) - c < p$ (respectively $\phi(X) - c > p$). At the market equilibrium p, there exists $\tilde{c} = \phi(X) - p$ such that all fishermen $c \leq \tilde{c}$ buy quotas up to their capacity $\bar{x}$, while the others $c \geq \tilde{c}$ sell all their quotas and stop fishing. The market clearing condition determines $\tilde{c}$ such that $X = \bar{x}G(\tilde{c})$. The equilibrium price is thus $p = \phi(X) - \tilde{c}$ which is the return of a quota in the fishery for threshold fisherman $\tilde{c}$.

The profit of a fisherman c with ITQs depends on whether he sells or buys quotas. A fisherman with cost $c \leq \tilde{c}$ buys $\bar{x} - \hat{x}$ units of quota to fish to his full capacity $\bar{x}$. His profit is therefore $\bar{x}[\phi(X) - c] - p(\bar{x} - \hat{x})$. His marginal cost is c for the first units of effort up to his quota endowment $\hat{x}$ and $c + p = c + \phi(X) - \tilde{c}$ beyond[16]. Those with $c \geq c^{FA}$ sell all their quotas at price $p = \phi(X) - \tilde{c}$ and thus obtain $p\hat{x} = (\phi(X) - \tilde{c})\hat{x}$ which is the threshold fisherman's profit from fishing (not including transactions in the quota market).

Now, to implement a fishing effort X, the $\hat{x}$ quotas assigned to the $G(c^{FA})$ fishermen must satisfy $\hat{x}G(c^{FA}) = X$ which, combined with the market clearing condition $\hat{x}G(\tilde{c}) = X$ yields:

$$\frac{\hat{x}}{\bar{x}} = \frac{G(\tilde{c})}{G(c^{FA})}.$$

Using the above relationship it is straightforward to write fishermen's profit as in (10) and (11), which formally shows that $\Pi^{FS}(c) = \Pi^{ITQ}(c)$ for every fisherman c. Therefore,

[16]The last equality is due to the market equilibrium condition $p = \phi(X) - \tilde{c}$.

the ITQ and FS regimes assign the same equilibrium profits to the fishermen for any targeted fishing effort $X < X^{FA}$. Hence, from the point of view of the profit-maximizing fishermen and the regulator, the two regulatory instruments are equivalent. We referee to both instruments as "market-based". In the next section we compare the market-based instruments with IQs.

6 Comparison of regulations

The market-based instruments perform better than IQs in three respects: (i) reduction of resource extraction, (ii) total welfare, (iii) individual welfare. They however lead to more unequal welfare distribution than IQs.

First, since the condition on the implemented fishing effort is more stringent in Proposition 2 than in Proposition 1, the FS and ITQ instruments make it possible to reduce fishing effort at least as much as IQs under the political feasibility constraint (without hurting any fishermen). Furthermore, some target fishing efforts can be implemented while satisfying the political feasibility constraint under FS and ITQs but not under IQs.

Second, by minimizing the total fishing cost, the market-based instruments FS and ITQs lead to higher total welfare. They both self-select the most efficient fishermen who fish under full capacity. In contrast the IQ regime keeps all fishermen in the fishery with a reduced activity. All regimes yield the same total return $X\phi(X)$ but the total cost of fishing under IQs is higher than under the market-based regulations, formally $\int_{\underline{c}}^{c^{FA}} \hat{x}cdG(c) > \int_{\underline{c}}^{\tilde{c}} \bar{x}cdG(c)$.

Third, for a same targeted fishing effort X, the market-based instruments yield strictly higher profits to almost all fishermen than do IQs. ITQs would yield the same profits as IQs if no quotas were exchanged. Yet as long as costs are heterogeneous, some transactions occur which strictly improve the parties' welfare. Fishermen who exchange quotas are strictly better-off doing so, which implies that their profit is strictly higher under ITQs than under IQs. Only the threshold fisherman $\tilde{c}$ who is indifferent to selling and buying quotas, and therefore might decide not to exchange quotas, has the same profit under both regimes.[17] All other fishermen obtain strictly more under the market-based regulations than under IQs.

We now examine the fairness properties of the three extraction regimes. Figure 4 below represents the distributions of profits extracted from the fishery under each regime.

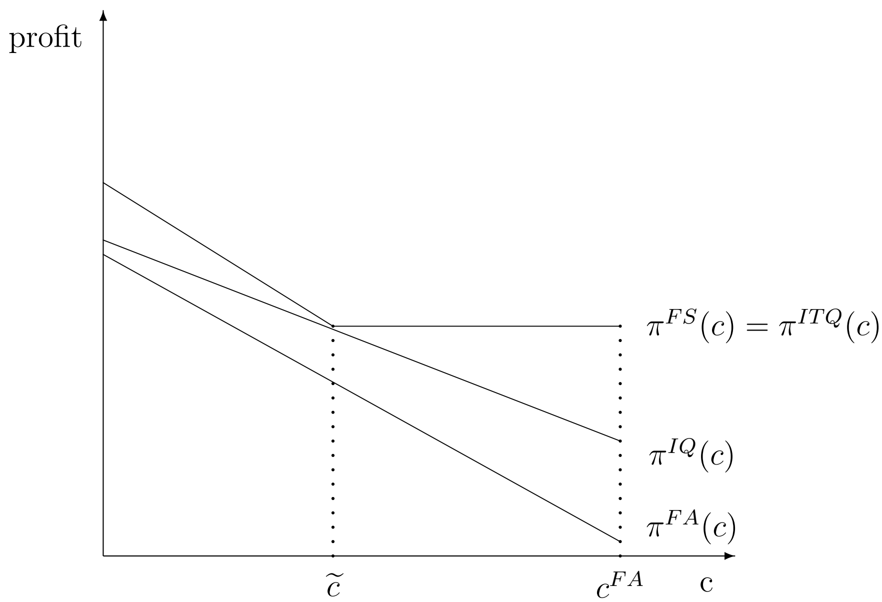

Figure 4. *Distribution of profits from the fishery*

The three curves are the profit levels $\pi(c)$ for every fisherman c under FA (the lower line), IQs (the middle line), FSs or ITQs (the upper kinked curve[18]). The equations of these curves are formally defined in (3), (15), and (10)-(11) respectively.

Our first concern is the distribution of welfare among fishermen. Introducing IQs clearly reduces inequality among fishermen as the slope of the profit line $\pi^{IQ}(c)$ is always lower than the slope of the profit line $\pi^{FA}(c)$. On the other hand, the FS scheme or ITQs have no impact on the distribution of welfare among the fishermen who fish under the

[17] Formally, combining (5), (11) and (15) shows that $\pi^{ITQ}(\tilde{c}) = \pi^{IQ}(\tilde{c}) = \pi^{FS}(\tilde{c})$.

[18] Recall that both regimes FS and ITQ yield the same equilibrium profits.

regulatory regime since the profit curves $\pi^{FS}(c) = \pi^{ITQ}(c)$ and $\pi^{FA}(c)$ have the same slope.[19]

A second fairness concern is the transfer of welfare between fishermen and non-fishermen. Under IQs, all welfare is shared among fishermen.[20] Under the FS scheme and ITQs, a share of this wealth is assigned to former fishermen through the subsidy or the quotas sold. Those agents are not involved anymore in the fishing activity. They are rewarded for not fishing but do not contribute to the welfare. Such a welfare distribution violates a fairness principle requiring that someone who contributes nothing to wealth obtains nothing. This principle, known as the "dummy axiom", is often invoked as a fairness criterion in the axiomatic literature on surplus sharing (Moulin, 2003).[21]

The above two fairness drawbacks are more severe with more stringent regulations (higher fishing effort reduction). A further reduction of X with IQs, which requires a lower number of individual quotas $\hat{x}$, reduces the slope of the profit line $\pi^{IQ}(c)$ for $c \leq \tilde{c}$. On the other hand, the same reduction of X with market-based regulations does not change the slope of $\pi^{FS}(c)$ and $\pi^{ITQ}(c)$ on the same range of c, and therefore inequality among fishermen is unchanged, but it increases the share of the welfare assigned to non-fishermen. Under FS, reducing X further requires an increase in both the access fee τ and the buy-back subsidy σ to exclude more fishermen. The threshold fisherman in Figure 4 moves left. Under ITQs, reducing the total number of quotas X leads to a higher equilibrium price in the quota market to the benefit of the quota sellers who do not fish at all. They obtain a higher return from selling their quota in addition to saving their costs (or obtaining the return from their outside option c).

[19] If c is an opportunity cost, the non-fishermen under the FS and ITQ regimes obtain the same payoffs from the fishery (i.e. the subsidy or the revenue from marketing quotas) but inequality among them remains the same than as under FA since their gain also includes their benefit from working full time on their outside option $c\bar{x}$.

[20] We abstract from the consumers', suppliers' and retailers' welfare since those stakeholders are absent in our model.

[21] For instance, the dummy principle was part of one the first characterization of the Shapley value due to Shapley (1953).

Compared to the free access benchmark, the fishermen who benefit the most from the market-based regulations are those who give up fishing. This is partly due to the fact that, since they quit the fishery, they save their costs c which is the highest. The FS and ITQ regulations not only transfer welfare to non-contributors but also assign the highest welfare improvement to them. In contrast, with IQs, the welfare improvement, although more modest, is more equally spread.

7 Conclusion

Free-access over-exploitation of common-pool resources can be avoided or at least mitigated through regulated extraction. Mainstream regulations include access fee and buy-back subsidies (FS), individual quotas (IQs) and individual transferable quotas (ITQs). When exploiters have heterogeneous extraction costs and constant return to scale, the extraction effort should be carried out by the low cost exploiters. This is made possible by the market-based regulatory instruments FS and ITQs. Instead, under IQs all users extract the resource with reduced capacity, thereby leading to higher total extraction costs. Thus quota transferability increases both total and individual welfare. We show that it expands the set of extraction rates (or extraction effort) that can be implemented without hurting the free access users of the resource. On the other hand, forbidding quota transferability reduces inequality among fishermen. It also precludes the transfer of part of the welfare to people who do not contribute to it. These two fairness properties might explain why IQs are widely used to regulate common-pool resources such as fisheries, hunting grounds or common-property forests, despite being inefficient.

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